International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 12-No.1 (2026) pp. 332-338

http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Effect of rough walls on hydraulic jump in arectangular open channel and appreciate experimental and theoretical analysis

Abdelouahed Brahimi[1]*, Zina Mansouri[2]

[1]Department of Civil Engineering and Hydraulic, University Kasdi Merbah Ouargla, Ouargla, Algeria
* **Corresponding Author Email:** brahimiabdelouahed@yahoo.fr - **ORCID:** 0000-0003-3910-0730

[2]Department of Civil Engineering and Hydraulic, University Kasdi Merbah Ouargla, Ouargla, Algeria
Email: mansouri.zina@univ-ouargla.dz - **ORCID:** 0009-0005-8841-4666

Article Info:

DOI: 10.22399/ijcesen.4779
Received : 03 June 2025
Revised : 10 December 2025
Accepted : 12 December 2025

Keywords

Hydraulic Jump,
Rough walls,
Conjugate depthratio,
Roughness,
Rectangular channel
Froude Number.

Abstract:

Hydraulic jumps have been attracted to many researchers for a long period of time because of its importance in designing hydraulic structures. Stilling basins are one of the possible solutions for hydraulic jump to dissipate kinetic energy to produce safe downstream flow, which causes no bed scour and bank erosion. Generally, the dimension of a hydraulic jump is taken as an indicator of the dimension of the stilling basin or as a design parameter. Lot of study has been made on hydraulic jump, and very limited studies have been reported in literature on the performance of hydraulic jumps formed in rectangular channel with rough walls, that way the paper is a valuable contribution to the subject. The purpose of the research work was to observe the phenomenon of the hydraulic jump,and to develop an understanding of the effect of roughness in an open horizontal channel. Also, to appreciate therelationship between the experimental results and the theoretical analysis based on the application of continuityand momentum principles. A series of experiments were carried out in a rectangular flume which consists of artificially roughenedwalls formed by circular balls with homogeneous and uniform shapes. The hydraulic jump parameters such as, pre jump depth, post jump depthand flow rate were measured for different roughness. During this study, sixty experimental runs were conducted by varying the Froude number, ranging from 2 to 17. It carries out on four sluice gate opening (h1 = 2, 3, 4 and 5 cm) with four different roughness elements of diameters (ε = 6, 8, 10 and 12mm) were introduced throughout the length of channel. The hydraulic jump considered in the present work have been controlled by sill with thirteen different sizes varying between 3 to 15 mm. The analysis of experimental data showed that the rough walls reduce the conjugate depthratiothan those on smooth walls. They have also, this parameter vary linearly with the Froude number and roughness where as other hydraulic jump characteristics are not. The analytical equation for the conjugate depthsratio as given byapplied theoretical the momentum equation, and itisadjusted well with the experimental data.Itis satisfactory for predicting the conjugate depth ratio of hydraulic jump on rough walls.

1. Introduction

One of the major uses of hydraulic jump is the energy dissipater. Hydraulic jump is formed at a section where low depth stream of high velocity strikes sufficient depth of liquid flowing with low velocity. This water is coming with high velocity. So, the kinetic energy of this flow is very high and it is capable of eroding the downstream surface. When the hydraulic jump forms, it can dissipate a large amount of energy by eddy formation and turbulence. That means by forming the hydraulic jump, the scouring at the downstream structure can be avoided.The hydraulic engineer takes care in design calculation development, the size and location of a hydraulic jump. More studies and researches on hydraulic jump have been done such as, the systematic analysis of hydraulic jumps along the hydraulically rough beds was first initiated by Rajaratnam (1968), defining the conjugate depth ratio as a function of the supercritical Froude number and the equivalent relative roughness with the experimental results. Subhasish et. al., (2003) has conducted extensive research work on the characteristics of turbulent flow in submerged jumps on rough beds. Another important contribution to the thematically relevant literature is the experimental and the theoretical work carried out by Kateb (2006) performing 70 experiments in a horizontal triangular flume measuring flow rate, pre jump depth, post jump depth and jump length on an artificially roughened bed varying from 4,53 mm to 8,73 mm. Ghamir (2013) studies the consequence of bed roughness on the characteristics of hydraulic jump carried out in a parabolic channel flume. Umut & Manousos (2020) have made exhaustive study on hydraulic jump characteristics, they are to assess and quantify the effect of channel bed roughness on hydraulic jumps based on sound physical theories.An experimental and theoretical analysis of the hydraulic jump evolving in a rough bottom channel was recently contributed byBrahimi et al. (2023).The core objectives of the investigation are to examine the characteristics of hydraulic jumps on rough walls and to compare the parameter with hydraulic jumps on the smooth horizontal walls and to find out a relationship between theconjugate depthratio for the rough channel with smooth horizontal in terms of the parameter such as upstream Froude number and roughness of the walls, and to compare the laboratory observations with that of the theoretical equation.

2. Theoretical Background

Figure 1 shows the various parameters related to a hydraulic jumpin this experiment.The dynamics of hydraulic jump is governed by the flow continuity and the momentum equation. From the theory we know that a hydraulic jump has the ability to dissipate large quantities of energy. Also, because the energy dissipation is high and the head loss is unknown, we cannot use the energy equation when dealing with a hydraulic jump. Therefore, we will need to use the momentum equation in the longitudinal direction to the control volume, between sections 01 and 02, it will be done:

$$P_1 - P_2 - F_R = \rho Q V_2 - \rho Q V_1 \qquad (1)$$

Where:

P_1 and P_2represent the hydrostatic pressure forces at the inflow and outflow of the control volume, respectively:

$P_1=\rho g \hbar_1 A_1$, with $\hbar_1=h_1/2$, and $A_1= bh_1$.

$P_2=\rho g \hbar_2 A_2$, with $\hbar_2=h_2/2$, and $A_2= bh_2$.

h_1:depth of flow just before the jump;

h_2:depth of flow just after the jump;

b:width of channel;

$\hbar_1$: depth of centroid of area at section 1-1 below free surface;

$\hbar_2$: depth of centroid of area at section 2-2 below free surface;

A_1 and A_2: area of cross-section at section 1-1 and section 2-2, respectively.

$F_R$represents the integrated walls shear stress on the horizontal plane coinciding with the rough surface. Proposed that F_R can be assumed to be proportional to the inflow hydrostatic pressure force, P_1 with a proportionality constant:

$F_R=CP_1$, with $P_1=\rho g \hbar A$, and $A=(b+2h_1) L_j$, and $\hbar=V_1^2/2g$

So, we can deduce that: $F_R = C\rho g(b+2h_1)L_j\left(\frac{V_1^2}{2g}\right)$

The right-hand side of the Equation (1) represents the momentum forces, in which, V_1 and V_2 are the supercritical and the subcritical flow velocities, respectively:

$V_1= Q/bh_1$ and $V_2= Q/bh_2$

The constant flow discharge is defined as Q and ρ is the density of the water.

After replacing all the expressions in the Equation (1), we can show that:

$$\frac{\rho g b}{2}(h_2^2 - h_1^2) = \frac{\rho Q^2}{b}\left(\frac{1}{h_2} - \frac{1}{h_1}\right) + C\rho L_j\left(\frac{Q^2}{2b^2h_1^2}\right)(2h_1 + b) \qquad (2)$$

SinceY = h_2/h_1: are known as conjugate depthratio. The Equation (2) can be into this form:

$$\left(\frac{1}{2} - \frac{Y^2}{2}\right) = \frac{Q^2}{gb^2h_1^3}\left(\left(\frac{1}{Y} - 1\right) + CL_j\left(\frac{1}{2bh_1}\right)(2h_1 + b)\right) \qquad (3)$$

Taking$K = \frac{CL_j*(2h_1+b)}{2bh_1}$=CL_j*(2h_1+b)/2bh_1 , and for rectangular channel:$Fr_1^2 = \frac{Q^2}{gb^2h_1^3}$. Where, Fr_1 is the upstream Froude number. So, the Equation (3) can be simplified as:

$$\frac{1}{2}(1 - Y^2) = Fr_1^2\left(\left(\frac{1-Y}{Y}\right) + K\right) \qquad (4)$$

$$\frac{1}{2}(1 - Y)(1 + Y) = \frac{(1-Y)}{Y}Fr_1^2\left(1 - \frac{YK}{Y-1}\right) \qquad (5)$$

Simplifying Equation(5) by taking the term (1-Y) from both sides of the equation, we have:

$$Y(1 + Y) = 2Fr_1^2\left(1 - \frac{YK}{Y-1}\right) \qquad (6)$$

Taking$C_R = \left(\frac{YK}{Y-1}\right)$, so finally Equation in this form:

$$Y = \frac{1}{2}\sqrt{8Fr_1^2(1 - C_R) + 1} - 1 \quad (7)$$
=1/2&?8Fr_1^21-C_R+1-1
(7)

It may be noted that when C_R=0, Equation (7) becomes the same as classical jump equationderived by Belanger (1841)for the hydraulic jump in the horizontal rectangular prismatic channel.
Indeed, this expression is theoretical because the shear force coefficient (C_R), can only be found from experimental data.

3. Materials and methods

3.1 Experimental Set-up

The experiment was carried out in the Hydraulics engineering laboratory, Department of Civil engineering, University ofOuargla. It was conducted in the rectangular channelof 10 m long, 0.25 m wide and 0.5 m high glass walled recirculating tilting flume.The channel has the facility to make it to a sloping channel as well as horizontal.It has smooth side glass walls however the roughness is designed. It isequipped with a flow meter for discharge measurement.The water reaches to the inlet tank of volume 5 × 2 × 0.5m^3 through the feeding pipe of diameter 150 mm provided with regulating valve andcentrifugal pumps which gives a maximum discharge of 44l/s.Figure 02 shows a view of the experimental set-up of a rectangular channel flume.

3.2 Preparation of roughness wall

The channel walls were roughenedby fixingcircular balls with homogeneous and uniform shapes. Four different types of artificial roughness elementshaving sizes (d) of 6 mm, 8 mm, 10 mm and 12 mm were used. The length of the roughened wall was limited to 2 m as shown in Figure 03.

3.3 Experimental procedure

The experiments were carried out in two stages, test runs on the smooth horizontal walls are covered in stage 01 whereas, the runs on rough walls in stage 02.In order to make the channel rough, the one type of roughness elements was firmly fixed on the walls. After opening the control valve, the sluice gate was adjusted to achieve a still water column at upstream of the sluice gate while trying to obtain a hydraulic jump in downstream side.In each experimental run upstream water depth, downstream water depth and flow rates were measured. This procedure was repeated for the other types of roughness elements(ε = 6, 8, 10 and 12mm).Several experimental runs are performed by varying the discharge and measuring the corresponding conjugate depthratio (Y). Moreover, the location of hydraulic jump can be determined by varying the gate openings (h_1 = 2, 3, 4 and 5 cm). Altogether 60 experimental runs were conducted for rough channel walls covering the Froude number(Fr_1)from 2 to 17.

4. Results and Discussion

As such the present study is carried out in the form of graphical representation to study the variation of various characteristics against Fr_1. Different hydraulics jump characteristics were evaluated to examine the different effects of hydraulicchannel roughness. The results are discussed in the following section.

4.1 Experimental observation

The experimental data of conjugate depth ratio(y_2/y_1) were compared with the upstream Froude number (Fr_1) for both horizontal smooth and rough channels as shown in figure 05.
From figure 05, it could be observed that (y_2/y_1) increases with an increase in (Fr_1) for both smooth and roughness, but (y_2/y_1) decreases with the increase in roughness.
This shows that there is a considerable impact of the height of roughness on (y_2/y_1) for a given (Fr_1) value, and it can be concluded that (y_2/y_1) is directly proportional to (Fr_1) and inversely proportional for roughness.

4.2 Data Analysis

Aiming to observe the relationship between the shear force coefficient (C_R) and the relative roughness (ε/b), the characteristic data of the experimental work conducted in this study is plotted in Figure 06. For that, a graph is designed to compare the variation of the term ([(Y+1)*2]^2 - 1) / (8) with the square Froude number for the four valve the roughness.In the light of this result, the plots lead to an observed relation between both terms of the form ([(Y+1)*2]^2-1)/(8) = d Fr_1^2, by comparing this relation with Equation (7), the term

Table 1:*The value of the Shear force coefficient (C_R)at differentrelative roughness.*

Roughnessε (mm)	**Relative roughness (ε/b)**	**Shear force coefficient (CR)**	**Regression coefficient (R^2)**
06	0,024	0,46	0,99
08	0,032	0,51	0,99
10	0,04	0,55	0,98
12	0,048	0,59	0,97

"d" represents the factor ($1-C_R$).The range of different shear force coefficient (C_R)evaluatedrelative to roughness is shown in table 1.In the data presentedby regression analysis, a linear relationship was derivedbetweenthe shear force coefficient (CR) and the relative roughness (ε/b), as shown in figure 07.Consequently, it can replace the shear force coefficient (C_R) in Equation (7), and finda new relationship for conjugate depthratio whichcan be rewritten in simplest form, as follow:

$$Y=\frac{1}{2}\sqrt{8Fr_1^2(1-14,11(\frac{\varepsilon}{b}))+1}-1,$$

for: 6 mm $\leq \varepsilon \leq$ 12 mm.

The experimental data of (y_2/y_1) were compared with the theoretical values as presented in Figure 08.Figure 08 shows a comparison between computed (y_2/y_1) using experimental data of the present study and observed (y_2/y_1). It can be seen from the figure that the existing formulations derived for hydraulic jumps on rough walls was be in goodagreement with the observed data.

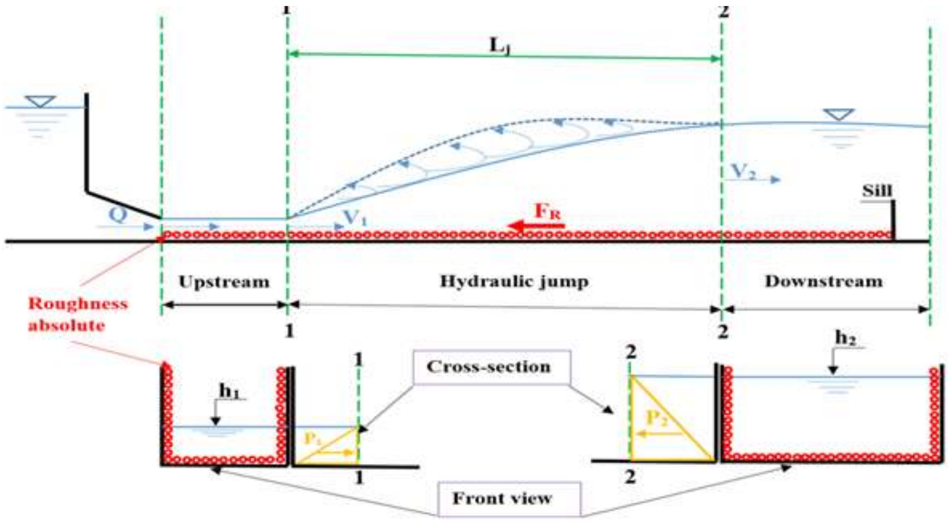

Figure 1:*Conceptual sketch for hydraulic jump over rough walls.*

Figure 2:*Photograph of the experimental set-up of a rectangular channelflume.*

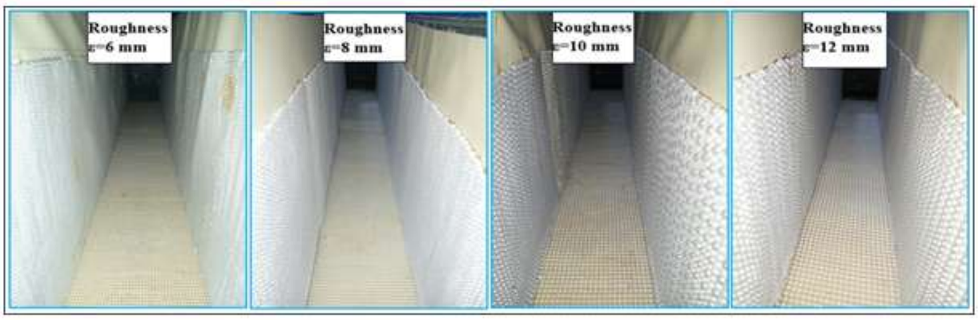

Figure 3:*Roughened wall arrangements.*

Figure 4: *Photograph of the hydraulic jump formation.*

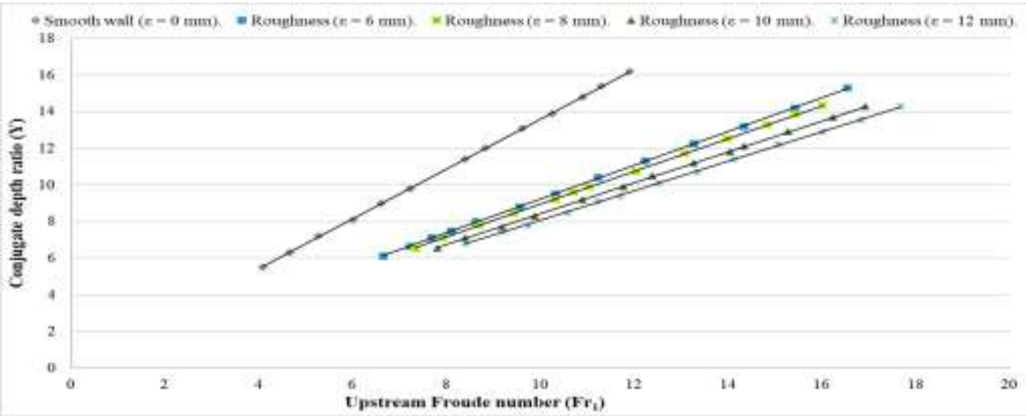

Figure 5:*Conjugate depth ratio versus upstream Froude number for different roughness.*

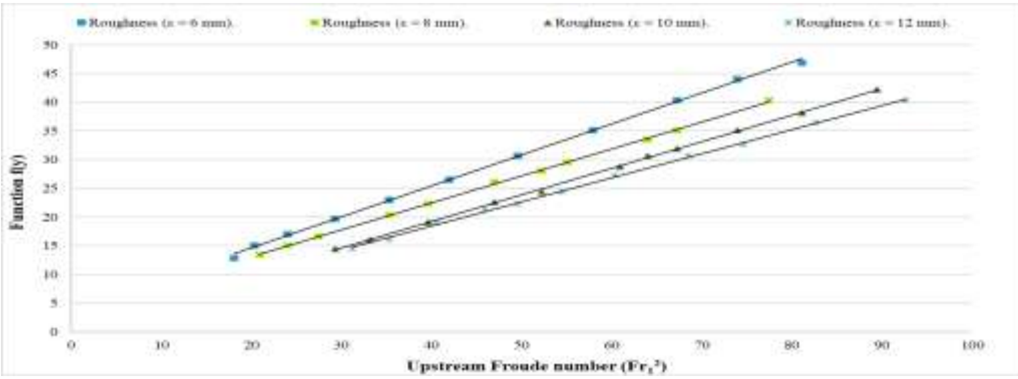

Figure 6:*Variation of the term ([(Y+1)*2]² - 1) / (8) with the square Froude number*

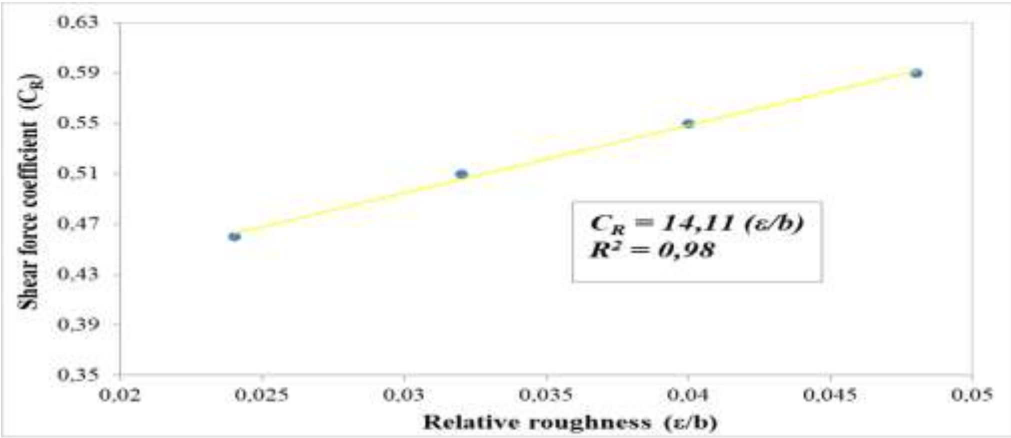

Figure 7*: The relationship between the shear force coefficient and the relative roughness.*

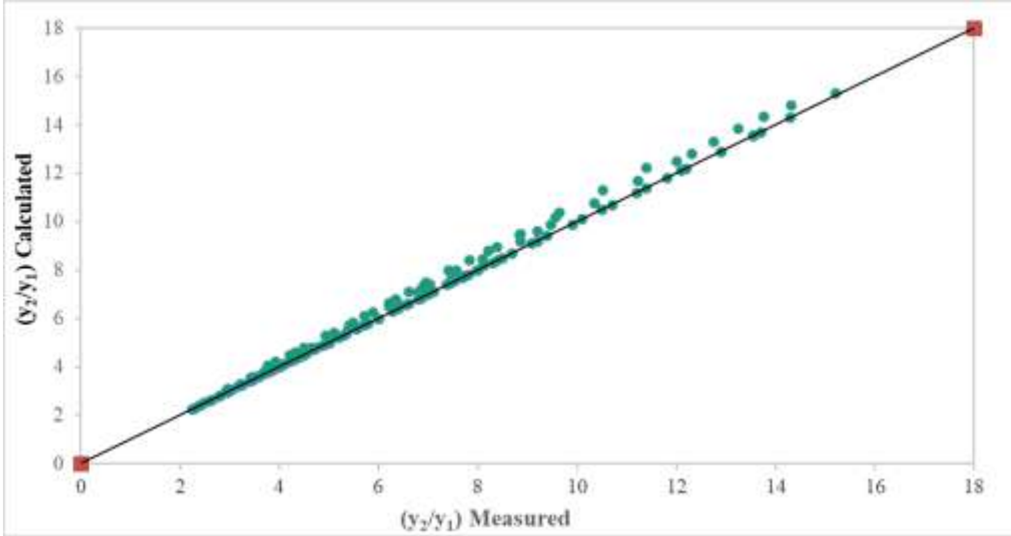

Figure 8: *Comparison of conjugate depth ratio between new equation developed with the measured value.*

5. Conclusions

The experimental and theoretical study of the hydraulic jump hydraulic jump experiment was accomplished in a rectangular open channel flume with rough walls leads to the following conclusions:

- A new theoretical equation was developed to relate the above parameters to conjugate depth ratio of hydraulic jumps on rough walls;
- The parameters such as conjugate depth ratio and Froude number were calculated using the experimental data and they were plotted in dimensionless form.It can be concluded that (y_2/y_1) is directly proportional to (Fr_1);
- For the same upstream Froude number, the variation between conjugate depth ratio and roughness is found to be inversely proportional;
- The graph of shear force coefficient (C_R) versus relative roughness (ε/b) indicated almost a linear relationship between the two parameters,it was found that maximum effect of roughness $\varepsilon = 12$ mm;
- The new semi-theoreticalconjugate depth ratio formula is derived in terms of the Froude number and the relative roughness, and it was also developed with the experimental data, reflecting the roughness effect on the conjugate depth ratio;
- A linear correlation is observed between the conjugate depth ratio calculated by the proposed relationship and experimental data.

Hence, this work outcome would lead to develop the knowledge required to analysis practical applications on hydraulic jumps. Further studies can be carried out in uniformly roughened wall which is ideal to natural river and irrigation channels.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.

- **Author contributions:** The authors declare that they have equal right on this paper.

- **Funding information:** The authors declare that there is no funding to be acknowledged.

- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Bejestan, M., Neisi, K. A New Roughened Bed Hydraulic Jump Stilling Basin, *Asian Journal of Applied Sciences*. 2009, 2(2), 436-445. doi: 10.3923/ajaps.2009.436.445.

[2] Brahimi, A., Kateb, S., Nouacer, B., Saggai, S., (2023), A theoretical and experimental study of the hydraulic jump evolving in a rough bottom channel, Tob Regul Sci, Vol. 9(1), pp. 3712-3722.

[3] Carollo., F.G., Ferro,V., Pampalone, V. Hydraulic Jumps on Rough Beds, *Journal of Hydraulic Engineering*. 2007, 133 (9), 989–999.doi: 10.1061/(ASCE)0733-9429(2007)133:9(989).

[4] Chow, V.T. *Open Channel Hydraulics*. United

States: McGraw Hill;1959, pp. 680.
[5] Daneshfaraz, R., Norouzi, R., Abbaszadeh, H., Kuriqi, A., Di Francesco, S. Influence of sill on the hydraulic regime in sluice gates: an experimental and numerical analysis, *Fluids*. 2022, 7 (7), 244. doi: 10.3390/fluids7070244.
[6] Ghomri, A., Riguet, F., Debabeche, M., (2013), Approche expérimentale de la longueur du rouleau du surface du ressaut hydraulique dans un canal profilé en U à fond rugueux, International Journal of Chemical and Petroleum Sciences, Vol. 2(1), pp. 20-26.
[7] Kateb, S., (2006), Ressaut hydraulique contrôlé par seuil évoluant dans un canal triangulaire à parois rugueuses, Thèse de Magister, Département d'Hydraulique, Université Mohamed Khider Biskra.
[8] Kateb, S., Ghomri, A., Debabeche, M. Experimental study of the hydraulic jump in a hydraulic jump in a sloped rectangular channel, *Journal of Fundamental and Applied Sciences.* 2018, 10, 216-225. doi: 10.4314/jfas.v10i1.16.
[9] Mahtabi., G., Chaplo., B., Azamathulla., H. M., Pal., M. Classification of Hydraulic Jump in Rough Beds, *Water*. 2020 12 (8), 2249.doi: 10.3390/w12082249.
[10] Rajaratnam, N., (1968), Hydraulic jumps on rough beds, Transaction of the engineering institute of Canada, Vol. (11), pp. A-2/ I-VII.
[11] Pagliara., S., Lotti., I., Palermo., M. Hydraulic jump on rough bed of stream rehabilitation structures, *Journal of Hydro-environment Research.* 2008, 2 (1), 29-38.doi: 10.1016/j.jher.2008.06.001.